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TRACKING STUDIES FOR JHF LATTICE

ALEXANDRE MOLODOJENTSEV

KEK

for RCS/MR lattice team

RCS-MACHINE PECULIARITIES

- *The design beam intensity is 8.3×10^{13} ppp*
- *Injection energy is 400 MeV*

<u>Incoherent tune shift should be less than (- 0.2)</u>

Transverse beam emittance after MT-injection is estimated as 214 π mm·mrad

THEN:

- *Collimator Acceptance is 324 π mm·mrad*
- *Physical Aperture is 486 π mm·mrad*

The dipole magnet GAP should be 210 mm

The quadrupole magnets in the straight sections should have LARGE aperture to allow beam manipulation during MT-injection, collimation and extraction: R_{POLE} ~ 20 cm , L_{eff} ~ 0.7…1.0 m

MR-MACHINE PECULIARITIES

- *Three-fold symmetric lattice*
- *Dispersion-free straight sections*
- *Bending MODULE consists of 3 FODO cells. ARC consists of 8 modules.*
- *Horizontal phase advance per MODULE is equal to 270 degree.*

  THEN:

  The horizontal phase advance per ARC is 6 times of 360 degree:

  - NO dispersion wave outside of ARC.

  - CANCELLATION of nonlinearity of chromaticity sextupole at the leading order.

- *Horizontal betatron tune should be near the 3rd order horizontal resonance line (SLOW extraction).*

- *Vertical phase advance per MODULE of 270 degree is preferable from the chromaticity sextupole point of view*

  BUT:

  Working point might be too close to the 0^{th} order coupling resonance.

- *To minimize the particle losses during the SLOW EXTRACTION α_H should be zero. It could be obtained if the vertical betatron tune is around 19.*

  THEN:

  Design working point is $Q_H = 22.30$ and $Q_V \leq 22.30$.

<u>Estimation of the incoherent tune shift</u> for the 3GeV beam with the beam intensity if 3.3×10^{14} ppp (B_F~0.27, Form-factor~1.7):

$$\Delta Q_{INCOH} \sim -0.15$$

MOTIVATION & SUBJECT:

DA of the RCS and MR without any magnetic field imperfections or alignment errors is determined by the intrinsic non-linearities of the magnetic fields of the ring magnets, in particular, the fringe-fields of the magnets and the non-linear field of the sextupole magnets used for the chromaticity correction.

TOOLS:

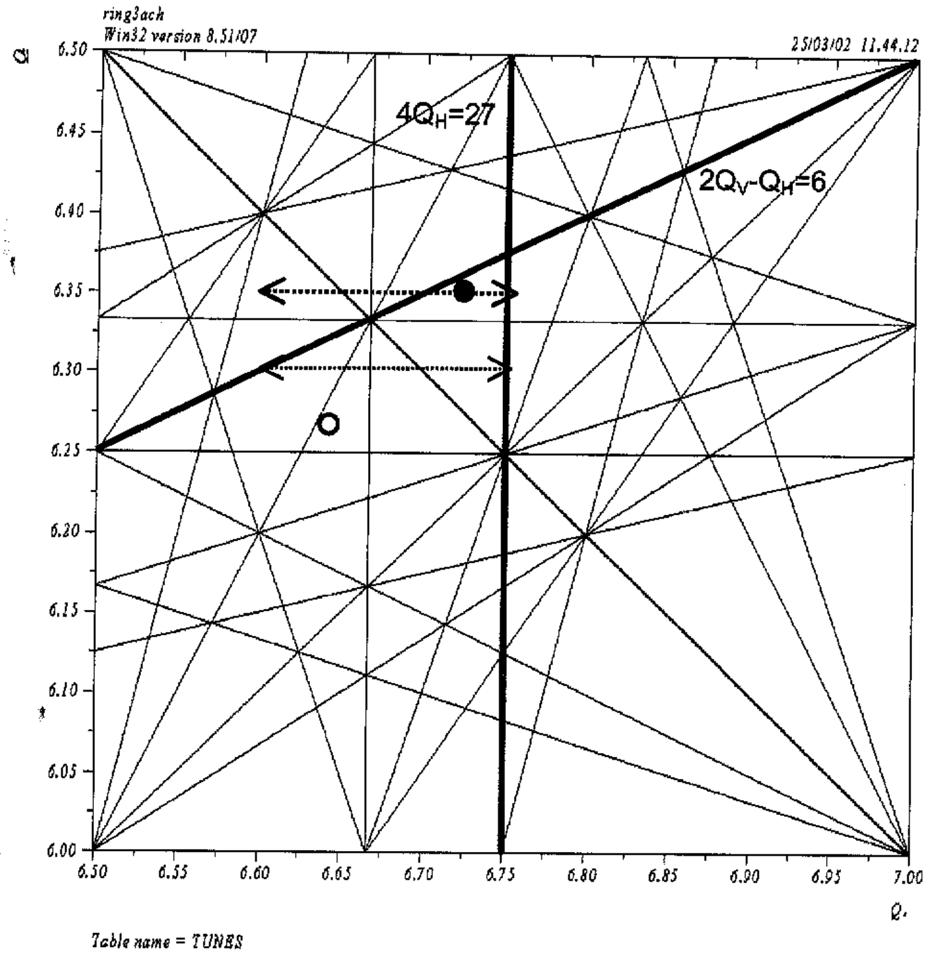
Symplectic particle tracking by using the high-order truncated Taylor map

COSY INFINITY

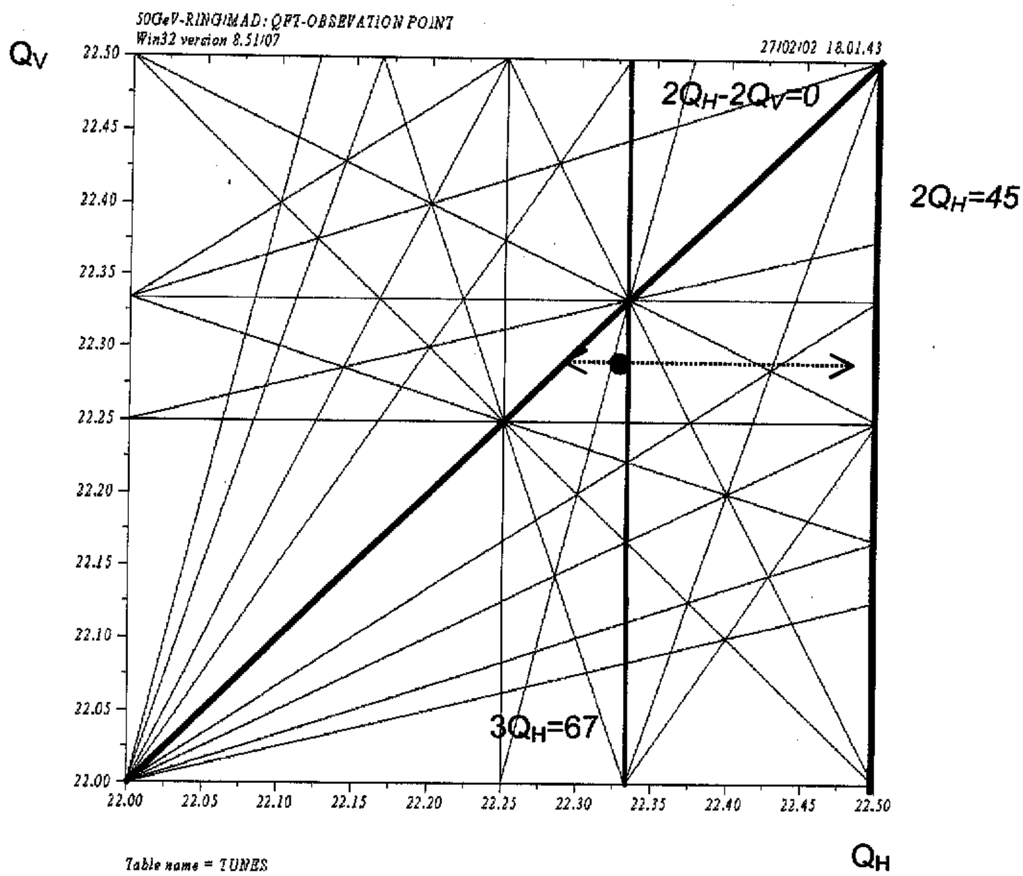
GOAL:

- *Study of influence of the STRUCTURAL resonances for RCS and MR*
- *Optimization of the Working Point to get MAXIMUM DA*

Betatron tune diagram of the 3GeV RCS for the design working point Q_H=6.72, Q_V=6.35



Betatron tune diagram of the 50GeV MR for the design working point Q_H=22.33, Q_V=22.28



Linear amplitude dependent detuning coefficients

(Q_H=22.33, Q_V=22.28)

	Fringe Field (Q-D-S)	*Sextupole Chromaticity Correction*	***<u>Combined:</u> Fringe Field + Chromaticity Correction***
a_{hh} $[m^{-1}]$	*30.834*	*180.064*	***207.6104***
a_{vv} $[m^{-1}]$	*35.813*	*135.128*	***161.7583***
a_{hv} $[m^{-1}]$	*30.388*	*171.553*	***198.1835***

Main detuning effect is determined by the <u>sextupole magnets</u> for the chromaticity correction.

De-tuning of the betatron tunes in the transverse phase planes for the design working point (Q_H=22.33, Q_V=22.28, W_{kin}=3GeV)

	Incoherent space-charge tune shift ($N_{ppp}=3.3\times10^{14}$)	*Linear amplitude dependent tune-shift at 1σ ($\varepsilon_{full}=54\pi\cdot$mm$\cdot$mrad)*	*Chromatic tune-shift after linear chromaticity correction (<u>$\Delta p/p=\pm0.01$</u>)*
Horizontal	*- 0.16*	5.5×10^{-3}	1.2×10^{-2}
Vertical	*- 0.16*	4.9×10^{-3}	1.7×10^{-3}

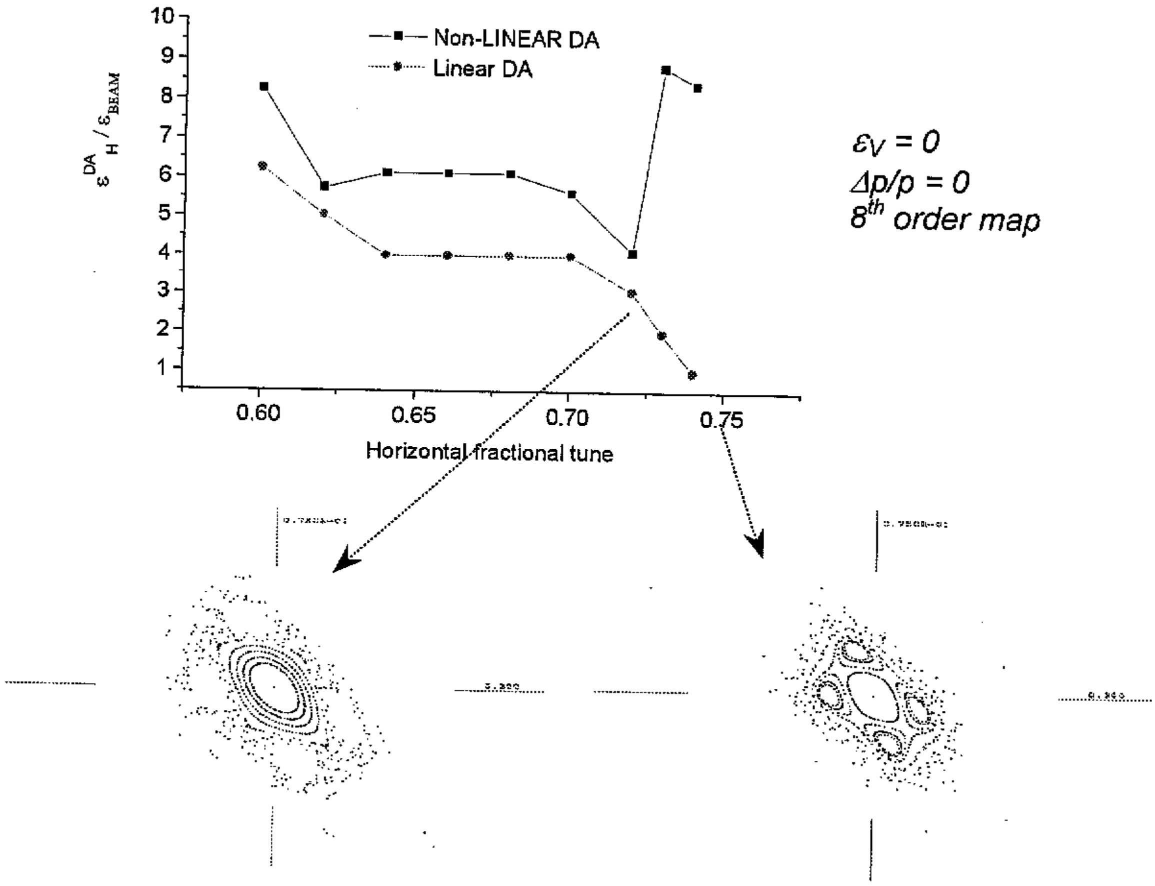
- *Linear amplitude dependent and chromatic tune-shifts for MR parameters are much smaller than the incoherent space-charge tune-shift.*

Definition of DA:

dynamic aperture (dynamic acceptance) of the synchrotron is determined as the maximum initial beam emittance that remain circulating in the chamber which has the horizontal and vertical sizes much bugger than the physical aperture (10 times bigger) at an observation point.

4^{th} order horizontal resonance $4Q_H$=27

excited by the non-linearities of the quadrupole fringe fields



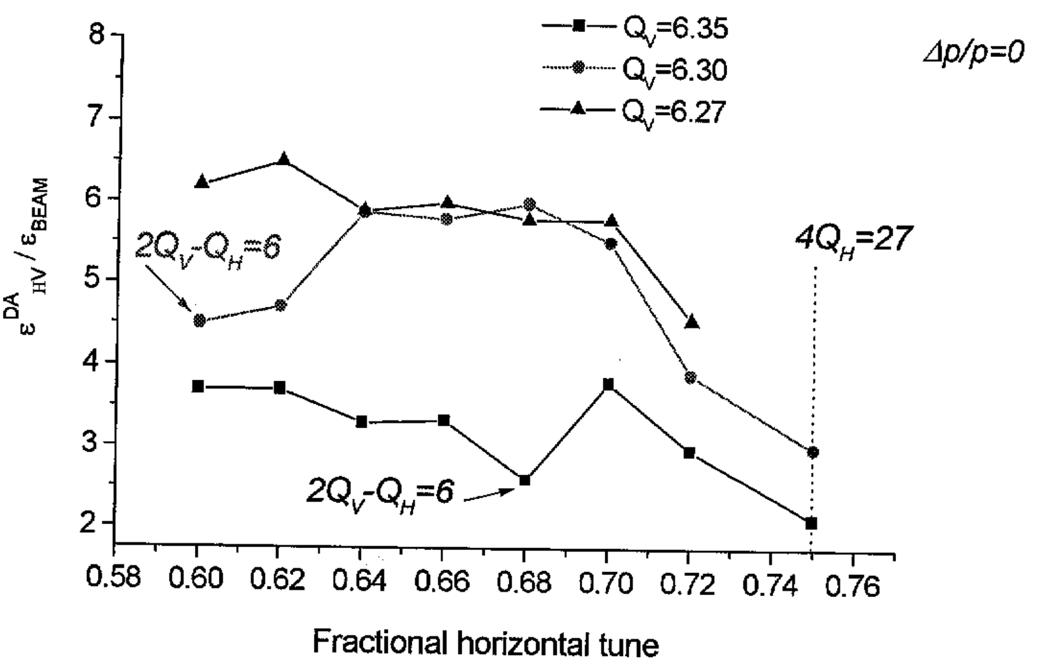
$\varepsilon_V = 0$
$\Delta p/p = 0$
8^{th} order map

3^{rd} order difference resonance $2Q_V - Q_H = 6$

Excited by...

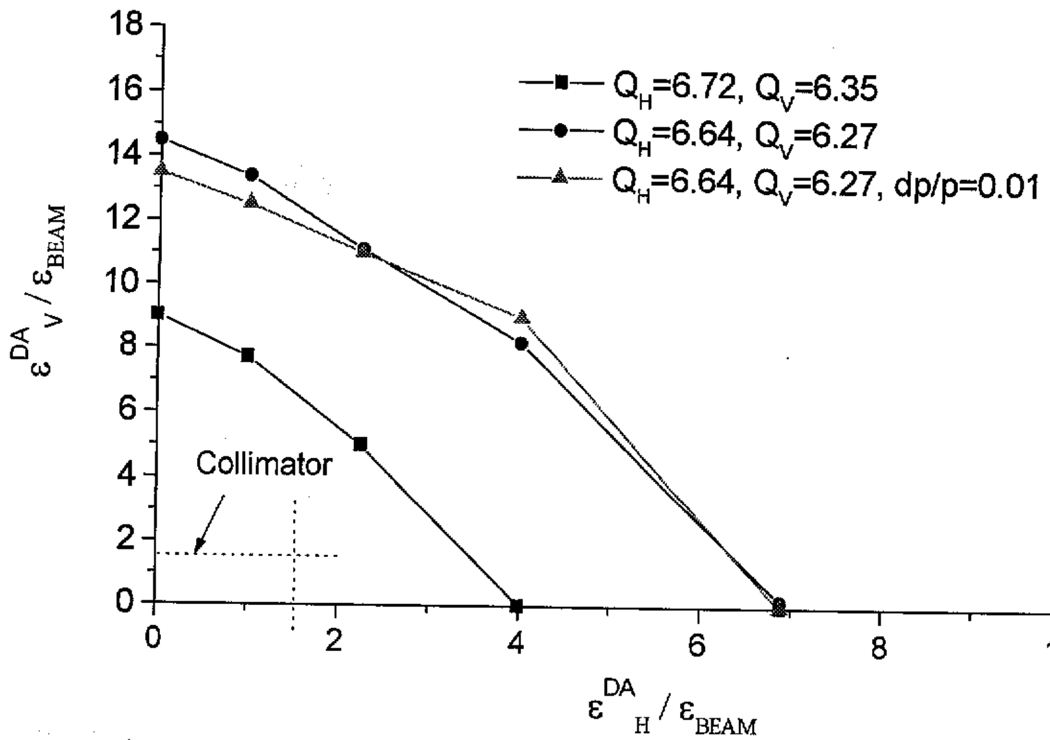
sextupole magnets for the chromaticity correction &

'sextupole' non-linearity of the fringe field of the ring dipole magnet



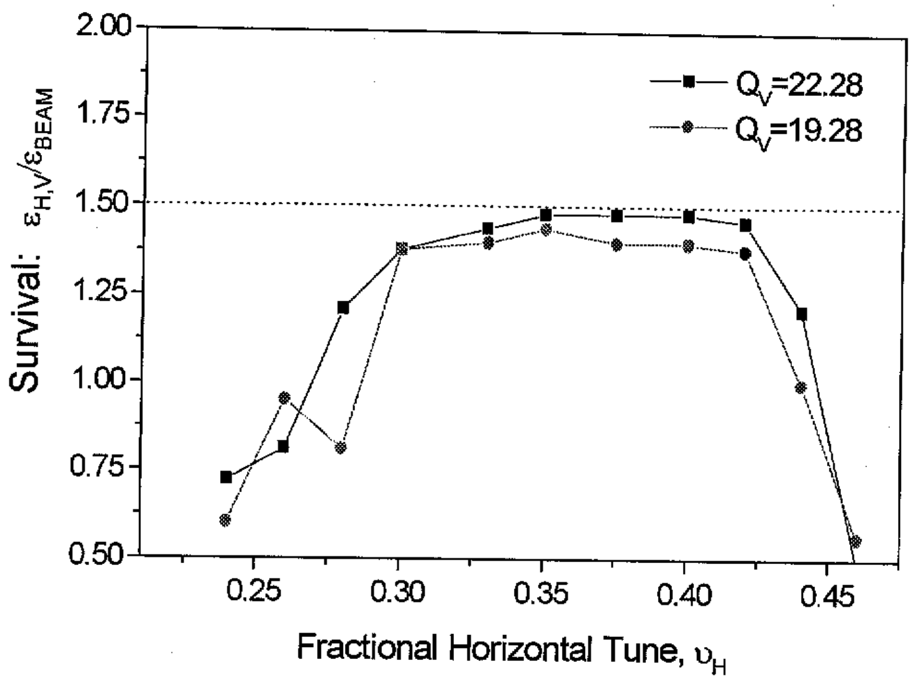
Changing of the vertical betatron tune allows INCREASE the on-momentum DA about 2 times eliminating the influence of the structural 3^{rd} order difference resonance of $2Q_V - Q_H = 6$.

Dynamic aperture of the 3GeV RCS for different working points



Survival of the beam in the physical aperture
during 1000 turns for different fractional horizontal tunes υ_H
around the design value (Q_H=22.33)
and different vertical tunes (Q_V=22.28 and 19.28).

Δp/p=0



- *For the horizontal betatron tune of 22.32…22.40 the maximum acceptable beam emittance, that survives in the collimator aperture, for both vertical betatron tunes (22.28 and 19.28) is about 75 π·mm·mrad.*

Linear amplitude dependent detuning coefficients (Q_H=6.72, Q_V=6.35)

	Fringe Field (Q-D-S)	Sextupole Chromaticity Correction	**Combined: Fringe Field + Chromaticity Correction**
a_{hh} [m^{-1}]	13.909	1.408	**14.113**
a_{vv} [m^{-1}]	12.824	25.625	**33.981**
a_{hv} [m^{-1}]	18.354	-22.997	**-6.748**

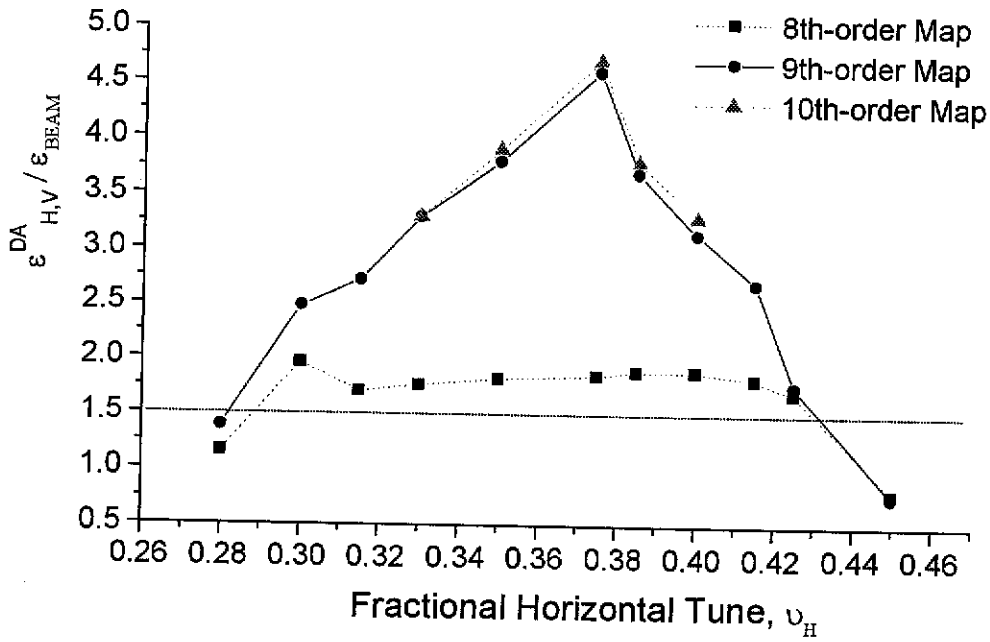
- *Main detuning effect is determined by the fringe fields of the ring quadrupole magnets*

De-tuning of the betatron tunes in the transverse phase planes

	Incoherent space-charge tune shift (N_{ppp}=8.3×10^{13})	Linear amplitude dependent tune-shift at 1σ (ε_{full}=214π·mm·mrad)	Chromatic tune-shift after linear chromaticity correction ($\Delta p/p = \pm 0.01$)
Horizontal	- 0.16	2.6×10^{-3}	9.7×10^{-3}
Vertical	- 0.16	1.5×10^{-3}	- 6.1 ×10^{-3}

- *Linear amplitude dependent and chromatic tune-shifts for RCS parameters are much smaller than the incoherent space-charge tune-shift.*

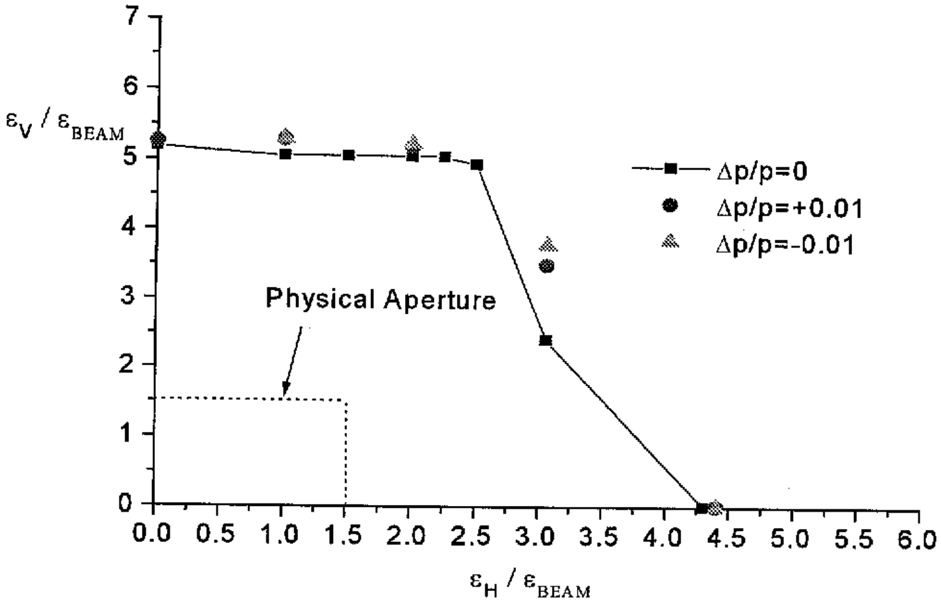
On-momentum DA for different fractional betatron tunes around the working point Q_H=22.33, Q_V=22.28.



- *In the case of the design working point DA is limited by the 4th order coupling resonance of $2Q_H - 2Q_V$=0.*

- *Maximum DA can be obtained if the horizontal betatron tune is located around Q_H = 22.37.*

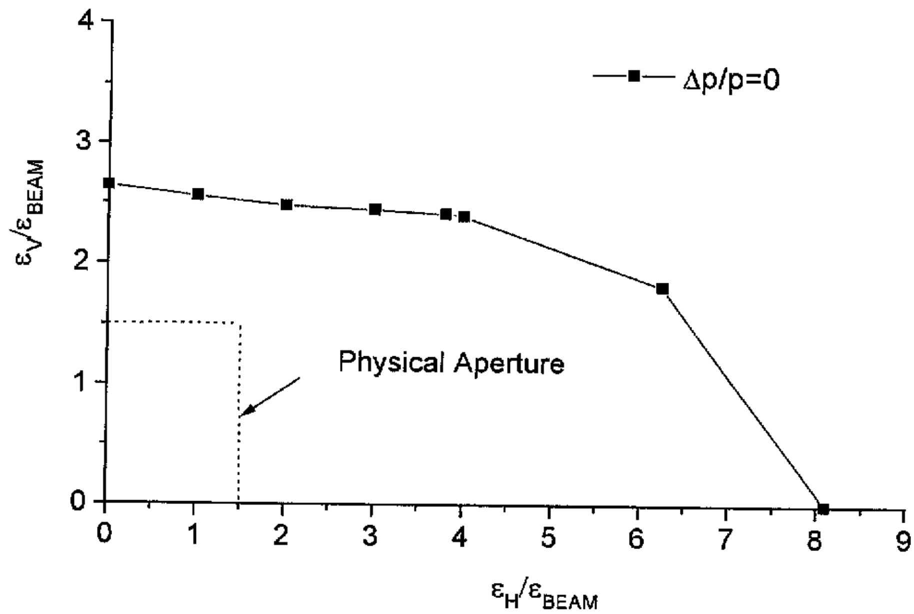
On-momentum and off-momentum DA determined by the intrinsic magnetic field non-linearities without any magnetic field errors for the design working point position Q_H=22.33, Q_V=22.28.



Physical Aperture ⇒ Primary Collimator: 81 π·mm·mrad

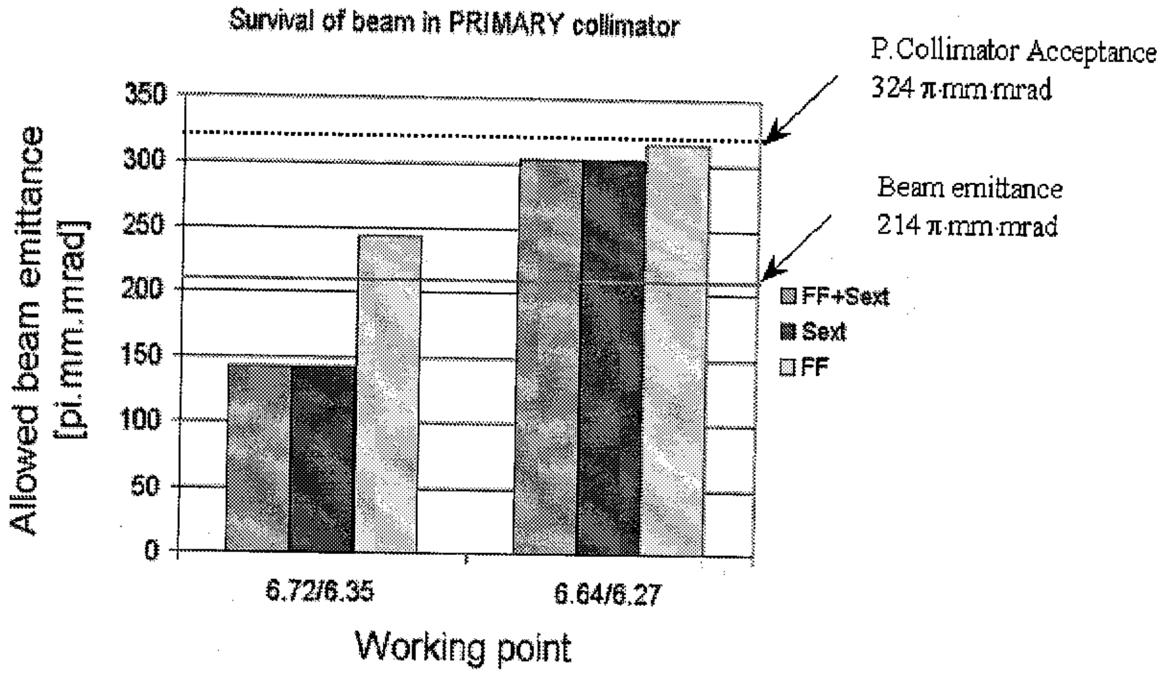
Beam emittance = 54 π·mm·mrad

On-momentum dynamic aperture determined by the intrinsic magnetic field non-linearities without any magnetic field errors for the working point of Q_H=22.33, Q_{V}=19.28.



- *For the working point Q_H=22.33, Q_V=19.28 the on-momentum DA also is bigger than the physical aperture.*

Survival of beam in the primary collimator for two working points



- *For the design working point (Q_H=6.72, Q_V=6.35) the maximum acceptable beam emittance is limited by 140 π·mm·mrad.*

- *Main contribution to the emittance limitation is determined by the non-linearities of the sextupole magnets for the chromaticity correction.*

CONCLUSION:

- *Main non-linearities for the JHF machines are determined by the lattice design:*

  3 RCS - Fringe fields of the QUADRUPOLE magnets;

  50 MR - SEXTUPOLE magnets for the chromaticity correction.

- *Limitation of DA for both machines is determined, first of all, by the intrinsic non-linearities of the magnetic fields of the ring magnets.*

- *Optimization of the Working point position allows to avoid influence of the structure resonances and improve DA.*

NEXT STEP OF STUDY:

Additional limitation of DA caused by magnetic field imperfections or alignment errors…..